Improving Signal Readout of an eEDM Measurement

Vedang Sumbre

Bachelor Project Presentation

29^{th} June, 2023

Outline

Introduction

We try to do a sensitive measurement for the electric dipole moment of an electron.

Introduction

We try to do a sensitive measurement for the electric dipole moment of an electron.

Theoretical value: $d_e \sim 1.0 \cdot 10^{-35}$ e cm [Y. Ema et al, 2022]

Introduction

We try to do a sensitive measurement for the electric dipole moment of an electron.

Theoretical value: $d_e \sim 1.0 \cdot 10^{-35}$ e cm [Y. Ema et al, 2022]

Best experimental limit so far: $|d_e| < 4.1 \cdot 10^{-30}$ e cm using HfF^+ [T. Roussy et al, 2022]

Introduction

We try to do a sensitive measurement for the electric dipole moment of an electron.

Theoretical value: $d_e \sim 1.0 \cdot 10^{-35}$ e cm [Y. Ema et al, 2022]

Best experimental limit so far: $|d_e| < 4.1 \cdot 10^{-30}$ e cm using HfF^+ [T. Roussy et al, 2022]

NL-eEDM target: $|d_e| < 5 \cdot 10^{-30}$ e cm using BaF [NL-eEDM, 2018]

How?

- Ground state of BaF has $F = 0$ and $F = 1$ hyperfine levels
- Optical pumping from the $F = 0$ level to the $F = 1$ level to create a superposition with a measurable phase difference
- Molecules counted using laser-induced fluorescence.

NL-eEDM setup

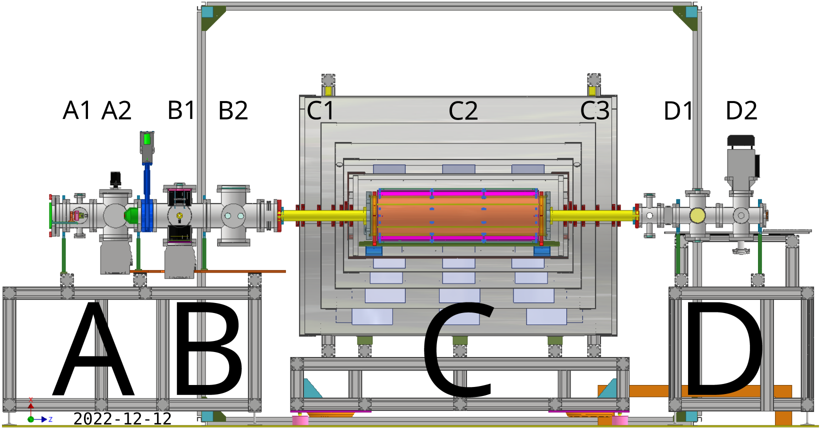


Figure 1: NL-eEDM fast beam setup

Motivation

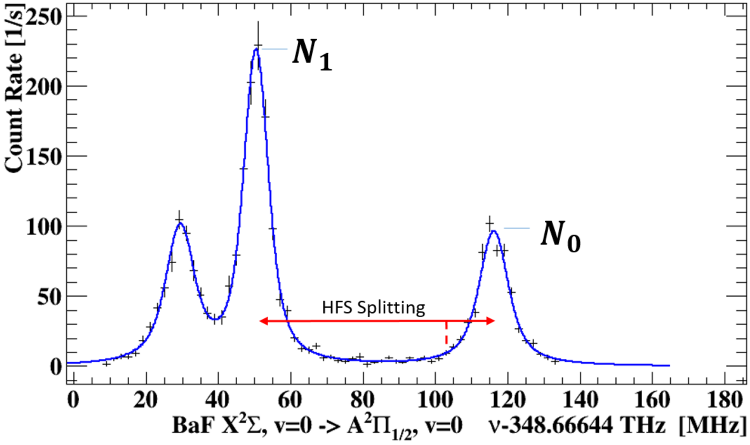


Figure 2: The photon count rate of transition as a function of laser frequency. Measurement from the NL-eEDM collaboration.

Research Goal

“Is it possible to use one laser to probe different frequencies simultaneously?”

Quick Answer

Yes.

Quick Answer

Yes.

A possible method is using acousto-optical modulators.

Zooming in at D1

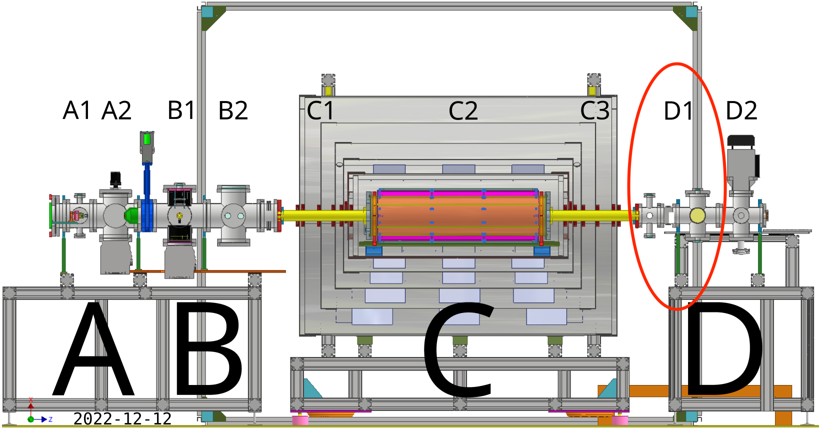


Figure 3: NL-eEDM fast beam setup

Zooming in at D1

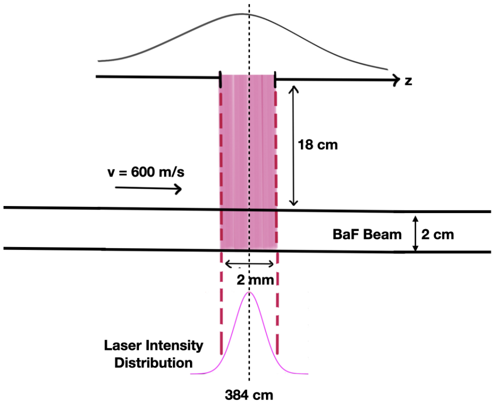


Figure 4: Schematic of BaF beam passing through a laser field at D1. NOT TO SCALE.

LIF and Depletion of Molecules

Molecules get depleted:

$$N(z) = N_0 - \int_{-\infty}^{z} \alpha I(z) N(z-1) dz \tag{3.1}$$

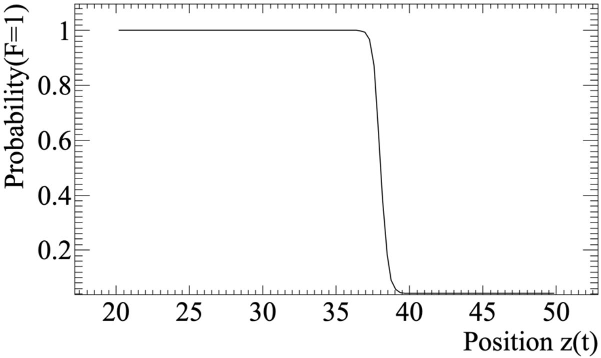


Figure 5: Simulated depletion with intensity set to $5 mW/cm^2$

LIF and Depletion of Molecules

Tempting to set a very high laser intensity. Bad idea!

LIF and Depletion of Molecules

Tempting to set a very high laser intensity. Bad idea!

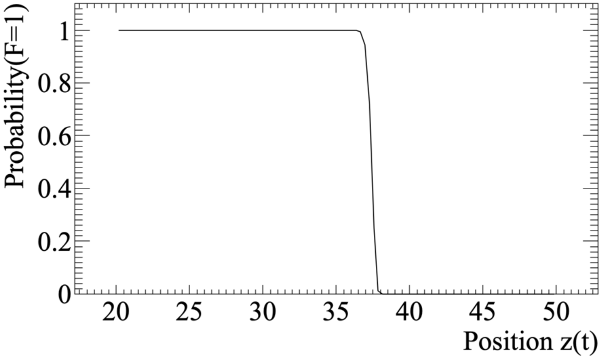


Figure 6: Simulated depletion with intensity set to $50 mW/cm^2$

LIF and Depletion of Molecules

Ideally require laser to be on resonance.

LIF and Depletion of Molecules

Ideally require laser to be on resonance.

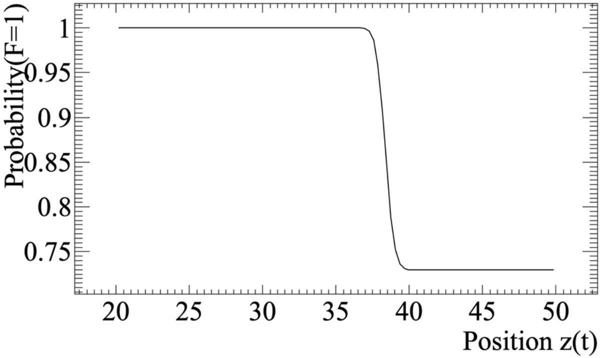


Figure 7: Simulated depletion with intensity set to 5mW/cm^2 and detuning 5MHz.

So, what do we need?

We want to have two laser fields:

So, what do we need?

We want to have two laser fields:

- 48MHz frequency difference

So, what do we need?

We want to have two laser fields:

- 48MHz frequency difference
- Intensity $\sim$ 1mW/cm^2

So, what do we need?

We want to have two laser fields:

- 48MHz frequency difference
- Intensity $\sim$ 1mW/cm^2
- Sufficient spatial separation

Acousto-Optical Modulators

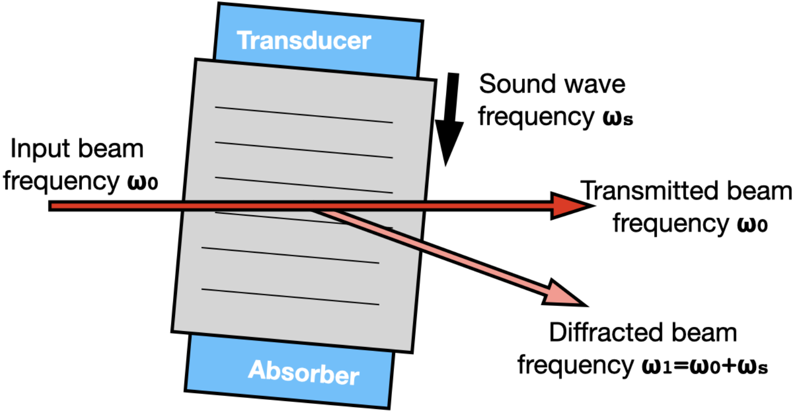


Figure 8: A schematic of a non resonant AOM.

Set up Picture

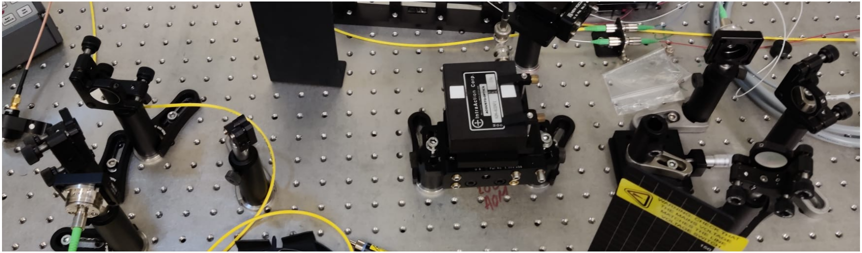


Figure 9: Picture of the set up

Setup Diagram

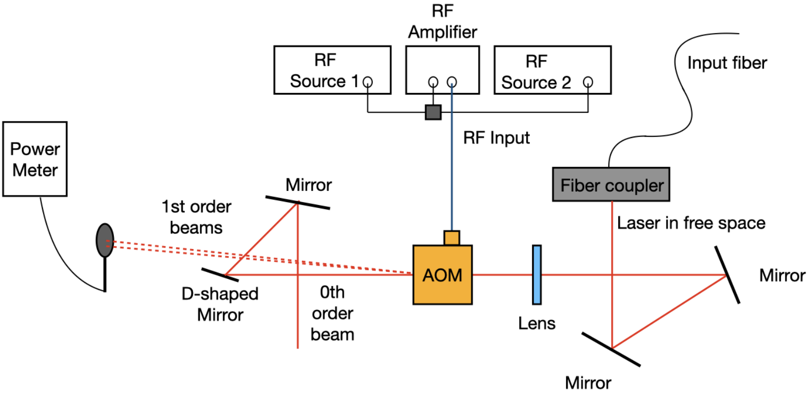
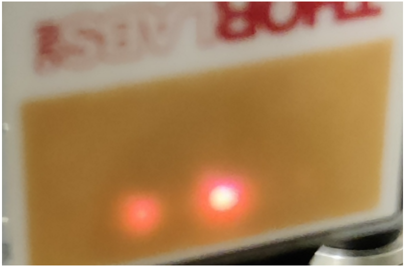
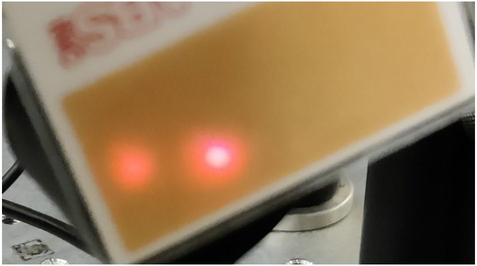


Figure 10: Schematic of the 200MHz AOM set-up

Results



(a) 0th and 1st order beams from RF source 1. Power of 1st order beam = 0.454mW.



(b) 0th and 1st order beams from RF source 2. Power of 1st order beam = 0.094mW.

Figure 11: Pictures of the 0th and 1st order beams from the two RF sources individually.

Results

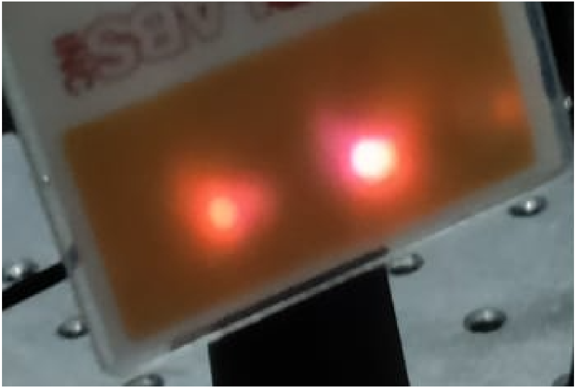


Figure 12: A picture of the IR reader card with both RF sources turned on using a 200MHz AOM.

Setup Diagram

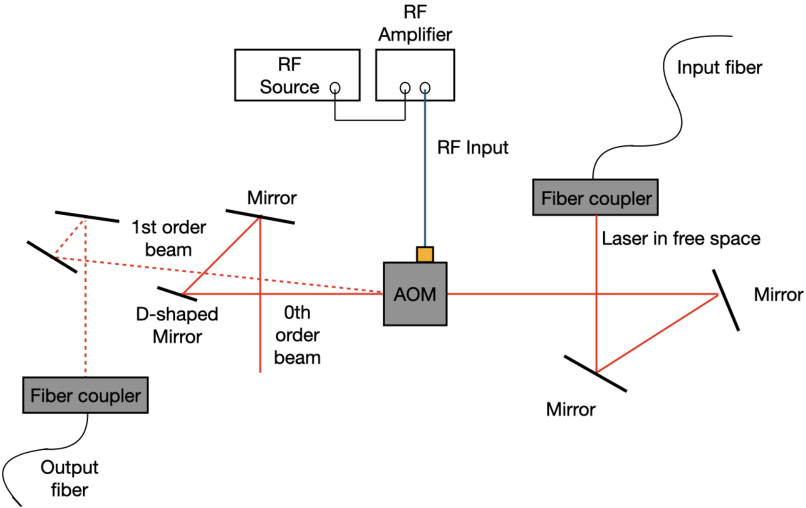


Figure 13: Schematic of the 40MHz AOM set-up

Results

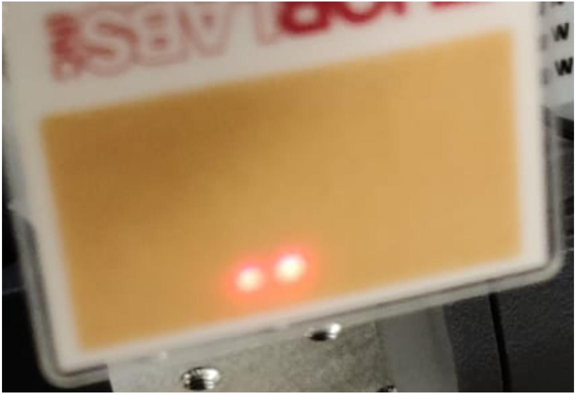
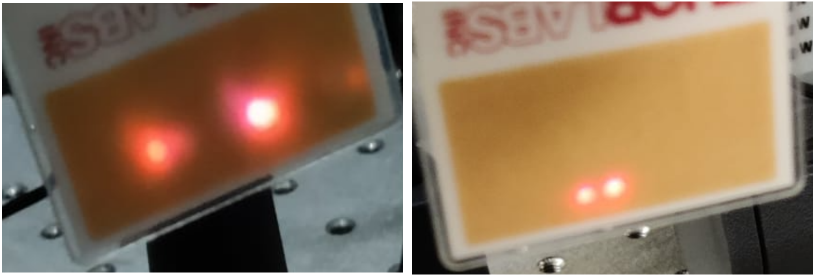


Figure 14: 0th and 1st order beams from 40MHz AOM.

Power of 0th order beam = 1.30mW
Power of 1st order beam = 2.11mW

Comparison of Results



(a) 200MHz AOM result

(b) 40MHz AOM result

Figure 15: Comparison of the results from the two AOMs

Power of beams from 200MHz AOM: 0.454mW & 0.094mW
Power of beams from 40MHz AOM: 1.30mW & 2.11mW

Conclusion

- Can we probe different frequencies at the same time?

Conclusion

- Can we probe different frequencies at the same time? **Yes**
- How?

Conclusion

- Can we probe different frequencies at the same time? **Yes**
- How? **Using an AOM**
- Which AOM is better?

Conclusion

- Can we probe different frequencies at the same time? **Yes**
- How? **Using an AOM**
- Which AOM is better? 40**MHz**

What's next?

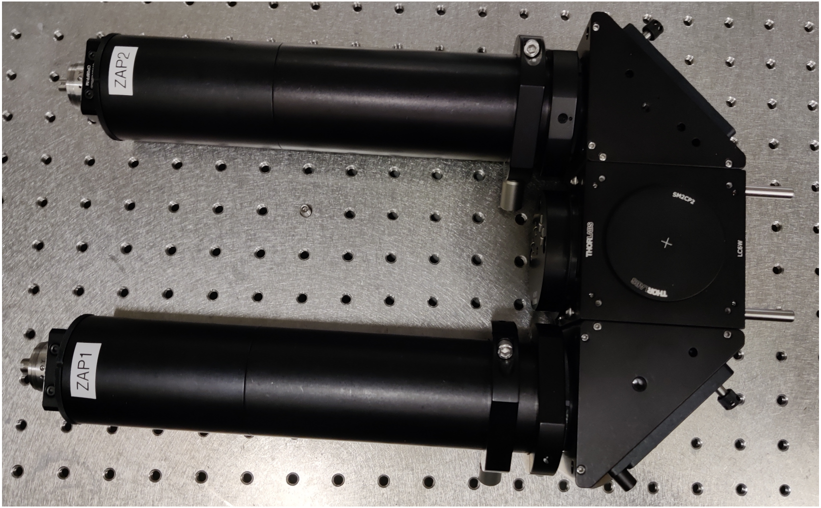
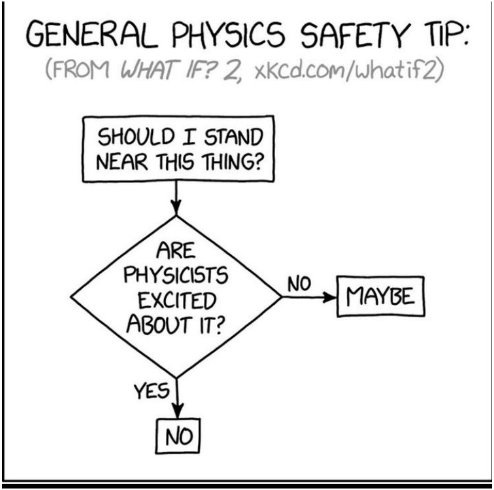


Figure 16: Implementation apparatus [O. Böll]

Thank you

Thank you for your attention!



Gaussian Beam Optics

Laser intensity can be written as Gaussian distribution:

$$f(z) = A \exp\left(-\frac{(z-\mu)^2}{2\sigma^2}\right) \tag{8.1}$$

Beam converges and diverges by angle θ from beam waist w_0:

$$w_0 = \frac{\lambda}{\pi\theta} \tag{8.2}$$

Rayleigh length : distance beam can go without divergence [Paschotta]:

$$z_R = \frac{\pi w_0^2}{\lambda} \tag{8.3}$$

Lorentzian Distribution

$$\mathcal{L}(\omega) = \frac{s_0}{2 * (1 + s_0 + \frac{\delta^2}{\gamma})} \tag{8.4}$$

γ is the decay rate of the molecule:

$$\gamma = \frac{1}{\tau} \tag{8.5}$$

The laser frequency detuning δ is defined as:

$$\delta = \omega_L - \omega_0 \tag{8.6}$$

PMT equations

Number of photons:

$$N_\gamma = P_{ext} * N_M \tag{8.7}$$

However, PMT efficiency considerations:

$$N_{F=1} = \varepsilon N_\gamma \tag{8.8}$$

$$\varepsilon = \Omega * \mathrm{QE} * \mathrm{transmission} \tag{8.9}$$

Tempting to set very high laser intensity. Bad idea!

SNR Considerations

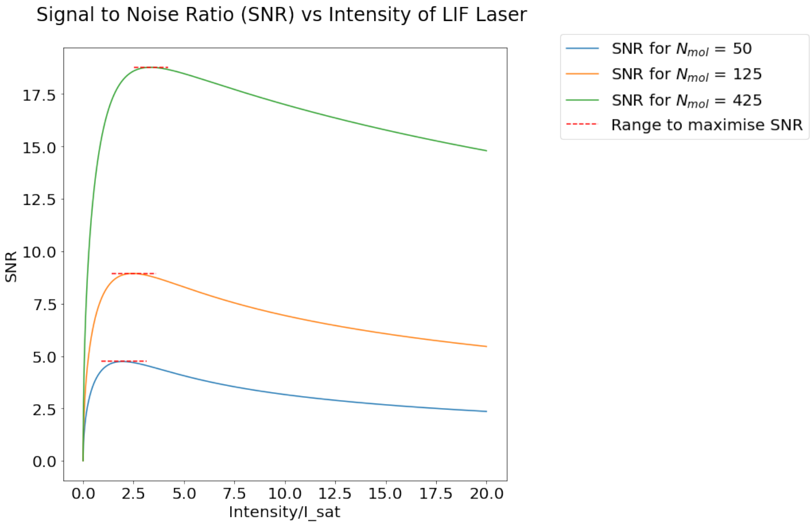


Figure 17: SNR vs LIF Laser Intensity, [E. Bobrova Blyumin, 2023]

Full setup